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A Century of Iowa Geology

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A CENTURY OF IOWA GEOLOGY

CHARLES KEYES

Prologue.

The first centennary of a science in Iowa is upon us. History of the sciences in the commonwealth now goes back beyond the span of our statehood. It transgresses a date when even a name for our state was yet unknown. In Iowa, by many years, claims to first recognition for geology antedate those of every other natural science. Curiously enough this earliest Iowa episode is also the most important geological event for the entire continent during a hundred years. It is even worldwide in some of its aspects. Nor are these early observations alone in their great significance. During the century just passed Iowa has been the field wherein a score or more far-reaching generalizations on geologic themes have had birth. That our state should be thus so intimately associated with the growth of American geology is surely a circumstance of much satisfaction to all Iowan scientists and laymen alike.

Amidst the multitudinous distractions of the world war Iowa's geological centennary has been allowed almost to pass unheeded. Yet, it is not too late to call attention to some of the outstanding features of a hundred years. Our accomplishments in this branch of science might have been much less.

At one time the great industrial importance of the Dubuque lead district naturally led to its systematic geological consideration. This, however, was more than two centuries after the discovery of the mineral there by Europeans, and twenty-five years subsequent to the first real geological investigation undertaken within the limits of our state. From the year 1634, when the French adventurer, Jean Nicollet,[1] penetrated from Quebec to southwestern Wisconsin, until 1839, when Dr. D. D. Owen made the maiden publicly supported survey of Dubuque, the lead region was of commercial solicitude only.

[1]Shea: Discov. and Explor. Mississippi Valley, p. 20, 1853.

INITIATION OF MODERN GEOLOGY IN THE NEW WORLD

Old Wernerian influences which dominated geological science throughout Europe and colonial America during the eighteenth century and the early decades of the nineteenth only barely touched Iowa. When William McClure, who, a hundred years ago, was long president of the American Philosophical Society, in Philadelphia, and who was in his day the foremost exponent of the German school in this country, prepared a general geological map of eastern United States, the formations afterwards called the Paleozoics are represented as reaching the Mississippi river.[2] Before these formations could be actually traced beyond, the determination of fossils from the Iowa side by Thomas Nuttall, forever barred the further spread of Werner's conceptions to trans-Mississippian territory. It is with these new and modern principles that Iowa entered upon her geological career.

By singularly happy chance Iowa was, in a very unusual way, closely identified with the establishment of modern geology. It was on Iowa soil that there was first application in the new world of the novel principles of identifying and correlating geological formations by means of the organic remains entombed within them. This was a full quarter of a century before the method, which has since become universal in use, was practiced anywhere else on the American continent. It was, moreover, the first attempt ever made to correlate by fossils geological formations of different continents.

Those remarkable precepts formulated by William Smith, which lie at the base of our accepted scheme of geological correlation and chronology, are thus practically tested in America, and in Iowa if you please, almost as soon as they are in England the land of their birth. That America should so early and from such an unexpected quarter as Iowa, furnish material aid in support of the newly announced principles is a fact worthy of more than passing notice. The circumstances are long since all but forgotten. In the few casual references made to them in after years either their true import is misunderstood or familiarity with the attendant conditions is entirely lacking. Both as the first successful application of modern geological principles in the new world and as the maiden effort, as it proved to be, at world-wide stratigraphical correlation, the event must ever remain one of the outstanding features in the history of geological science.

Nuttall's paleontological correlations antedate by fifteen years

[2] Trans. American Philos. Soc., Vol. VI, p. 411, Phila., 1809.

Samuel Morton's similar efforts on the Tertiaries of our Atlantic coast, commonly regarded as the initial attempts in America along these lines.[3] By two decades they were in advance of the first work of that pioneer paleontologist, Lardner Vanuxum.[4] They anticipate by a full generation the famous investigations of Thomas Conrad and James Hall, of New York. Nuttall was an English printer who came to this country in 1808, and who during the following year made a western trip in quest of scientific information, reaching the Mississippi river at Prairie du Chien and descending the great stream in canoe to St. Louis.[5]

FIRST RECOGNITION OF CARBONIC ROCKS IN AMERICA

Another conspicuous feature of rather peculiar significance connected with this earliest geological investigation within the boundaries of our state, is the determination of the presence of rocks of Carbonic age for the first time in this country. In the course of his explanations of the geological characteristics along the banks of the Mississippi river, Nuttall rather naively observes that he is "Fully satisfied that almost every fossil shell figured and described in the *Petrifacta Derbiensia* of Martin was to be found throughout the great calcareous platform of Secondary [Paleozoic] rocks exposed in the eastern part of the Mississippi valley."[6] Thus by means of the contained organic remains he parallels these Mississippi limestones with the Mountain limestones of the Pennine range of England, to which several years later Conybeare gave the title by which we now everywhere know them.

At this late day we can hardly appreciate the scant state of knowledge concerning the geological column a hundred years ago. When Nuttall arrived on the scene Iowa-land was a perfect *terra incognita*. No scientist had yet laid eyes on the field. Along the Mississippi river, as we now know, the Englishman collected fossils from rocks which are mainly if not entirely Early Carbonic in age. So his identifications of forms were with a few possible exceptions doubtless correct. Moreover, it must be remembered that at that time and for many years afterwards the inferior rocks of not only this country but throughout Europe were entirely undifferentiated. The great succession of older stratified formations which were subsequently successively separated from one another were jumbled together under the title of Transition Group. It was not until a

[3]Jour. Acad. Nat. Sci. Philadelphia, Vol. VI, pp. 72-100, 1829.
[4]Jour. Acad. Sci. Philadelphia, Vol. VI, pp. 59-71, 1828.
[5]Observations on Geological Structure of Valley of the Mississippi; Jour. Acad. Nat. Sci. Philadelphia, Vol. II, pp. 14-52, 1821.
[6]Jour. Acad. Nat. Sci. Philadelphia, Vol. II, pt. i. p. 14, 1821.

full generation later that out of them, in Britain, Murchison, Sedgwick and Lonsdale resolved the Silurian, Cambrian and Devonian systems, titles which still hold today.

The analogy established by Nuttall between the general Carbonic section of Iowa-land and of the upper Mississippi valley and that of northern England is one of far-reaching consequence. Its great significance is pointed out by Owen a couple of decades later. Its historic value grows with the advancing years. It is one of the important geological discoveries in America.

These early interpretations were the means of actually and correctly determining the true positions and the biotic relations of the Carbonic rocks of the continental interior a half century before their geologic age was otherwise generally admitted. These Mississippian limestones, as the rocks are now designated, remain today as compact and as sharply delimited a sequence of geologic terranes as they appeared when first recognized in that memorable summer of 1809.

DISCOVERY OF AMERICAN CRETACIC DEPOSITS

Credit for another shrewd guess in world-wide correlation is to be ascribed to Nuttall. On a second trip on western waters, in 1810, he ascended the Missouri river to the Mandan villages, near the Big Bend, where Bismark, North Dakota, now stands. This voyage was made in company with John Bradbury, a Scotch naturalist. Especial mention is made of the Omaha Indian settlement situated below the mouth of the Big Sioux river.

A short distance upstream from the Omaha tepees Nuttall examined strata exposed in the bluffs which by means partly of the fossils and partly of lithologic resemblance he was inclined to refer to the Chalk Division of the Floetzgebirge, or Secondary rocks, of northern France and southern England.[7] So utterly dumfounded was this observing naturalist at finding real chalk so far from home that he hardly believed his own senses; and he entered into prolix argument in support of his determinations, yet remained to the last somewhat skeptical as to the correctness of his conclusions.

This is the earliest definite recognition of beds of Cretacic age in America. It precedes by a decade and a half the separation, by John Finch, of the newer Secondary rocks from the Tertiary section in the Atlantic states; and Lardner Vanuxem's and Samuel Morton's references of the same deposits to the Cretaceous age. Thus, also, is another great succession of one of our main geologic

[7] Jour. Acad. Nat. Sci. Philadelphia, Vol. II, pt. 1, p. 25, 1821.

periods discovered in a then remote part of our continent years before it is recognized in the East.

PRIMARY GEOLOGICAL CROSS-SECTION OF MISSISSIPPI VALLEY

Iowa was still primeval wilderness when first attempts were made to decipher the geological substructure of her broad prairies. In those early days the construction of a geologic cross-section from verge to verge of the vast Mississippi valley was an undertaking of no mean proportions. Following closely in the Wernerian footsteps of William McClure, father of American geology, Dr. Edwin James, who was surgeon, botanist, and mineralogist of the famous Long Exploratory Expedition to the Rocky Mountains, in 1819-20,[8] endeavored to extend McClure's section of the forty-first parallel, from the Alleghany Mountains to the Rocky Mountains.

Crude as the results appear at this day the simplicity of structure largely obviates serious error that otherwise might have been made. This parallel of latitude crosses the southern part of our state. Although Doctor James afterwards lived in Iowa, near Burlington, for more than a quarter of a century, at the time of the Long trip he traversed only the southwestern corner of the state. A similar cross-section was executed along the thirty-fifth parallel, which was intended to be a continuation of McClure's "Fifth" section.

In spite of his strong Wernerian predilections an important observation was the recognition of the coal formation. He made the prediction that some day these coal deposits would prove to be of very great value.

The striking feature brought out in the cross-section was the fact that throughout the breadth of the Mississippi basin the strata reposed practically undisturbed. This condition contrasted strongly with the tilted beds at either side. Thus was early although faintly adumbrated that basin-shaped form of the continent of which in later years Dana made so much.

As a matter of fact James' work was really one of the larger undertakings in the geological field of his day.

TERRANAL CORRELATION OF ORE DEPOSITS

Although erroneous in principle early application of the idea that mineral deposits are in some way genetically connected with specific geological formations under certain limitations proved to be unexpectedly fruitful in ore exploration. Its first presentation was a

[8] Account Exped. Pittsburg to Rocky Mts., in 1819-20, Vol. I, Philadelphia, 1823.

direct result of investigations in the Dubuque lead region. So far as we know the conception originated with Henry Schoolcraft, a naturalist of singularly wide accomplishments, who was the narrator and mineralogist of the Cass expedition to the sources of the Mississippi river in 1820.

On the return journey of the Cass exploring party Schoolcraft left his companions when Prairie du Chien was reached and made a side trip to the Iowa mineral district. Of this he gave the best detailed description up to that time and for a generation thereafter. This traveler had previously investigated the lead mines of southeast Missouri and had published full accounts of them and of the methods of mining and treating the ores.

As an outcome of his Iowa visit Schoolcraft conceived the notion that the Iowa and Missouri mineral belts were genetically related. He fancied that the lead-bearing strata of the two widely separated localities were stratigraphically identical.[9] In this opinion he was doubtless largely influenced by Nuttall's parallelism of the Iowa rocks with the English lead-bearing rocks of Derbyshire. The fact that he designated the formation the Metalliferous Limestone is significant. In after years both Keating and Featherstonough fell into the same error by calling the Iowa lead rocks the Magnesian Formation and the Galeniferous Limestone, in commemoration of the fact that in England the same names were used for the lead-bearing formations above the Mountain Limestone, which were regarded as Permian in age. The statement was repeated as fact for many years afterwards.

Schoolcraft's idea was from time to time elaborated, until its necessary consequences had to be finally supported by the assumption that the ore bodies were primarily deposited under the influence of favorable local currents on the floor of the ancient ocean. In some form or other this curious notion quite generally prevailed for more than half a century. Even at the present day it is in some quarters seriously upheld.

With certain severe limitations Schoolcraft's theory is still one of the most useful geological tenets in mining.

GEOGRAPHIC DELINEATION OF IOWA

So soon as Congress, in 1838, made provision for erecting a new territory under the name of Iowa the engineering corps of the United States army sent out a party to prepare a detailed map of

[9] Narrative Journal of Travels etc., to Sources of Mississippi River, Cass Exped., 414 pp., Albany, 1821.

the country. This work was intrusted to Joseph N. Nicollet, a French geographer.

Along with his geographic and engineering abilities Nicollet possessed a keen appreciation for matters geological. His practical familiarity with fossils was quite extraordinary. He was acquainted with Murchison's then new classification of rock-terranes. Notwithstanding the fact that his strictly geological observations in Iowaland were incidental only to his special work in hand, he presented a wealth of interesting items concerning the geology of the region. He was the first to announce that in the lead district of Dubuque the main mineral-bearing formation should be correlated with Locke's Cliff limestone of Ohio, and Hall's Trenton limestone of New York. Calcareous rocks outcropping near the mouth of the Big Sioux river were shown, by microscopical examination, to be composed largely of minute shells like those occurring in typical chalk and to be of Cretacic age.

Nicollet's physiographic descriptions are notable productions. His finished map was a real marvel.[10] According to the high authority of Warren this map was "One of the greatest contributions ever made to American geography."

PRIMAL CLASSIFICATION OF IOWAN GEOLOGICAL FORMATIONS

First efforts to arrange the rock terranes of Iowa in orderly succession according to modern criteria was by Dr. D. D. Owen, in 1840.[11] This scheme grew out of his examination of the mineral lands of the Dubuque district, as a part of a comprehensive plan adopted by the Federal government to separate the mining properties from those which were not ore-producing.

Owen's subdivision of the Cliff limestone into Upper, Middle and Lower sections proves to be valid. This scheme having passed every test stands today essentially as originally proposed. These subdivisions are respectively the Devonic, Siluric and Ordovicic successions of later nomenclature. In the second and revised edition of the report these names actually appear.[12] Thus four major subdivisions of the Paleozoic sequence are upon strictly faunal grounds firmly established in the West. The rocks of the Cambric system, as it is now called, could not very well have attracted Owen's

[10]Rept. Intended to Illustrate a Map of the Hydrographic Basin of the Upper Mississippi River: Twenty-sixth Cong., 2nd Sess., Sen. Doc. Vol. V, pt. ii, No. 237, 177 pp., 1843.

[11]Rept. Geol. Expl. Iowa, Wisc. and Ill.; Twenty-sixth Cong., 1st Sess., House Doc. No. 239, 161 pp., 1840.

[12]Thirtieth Cong., 1st Sess., Sen. Ex. Doc. No. 57, 1848.

attention at this time, since they are exposed mainly outside of the field in which he then worked.

At a somewhat later date[13] Owen further elaborated upon his classificatory scheme and instituted a parallelism between the Iowa and the New York sections.

INTRODUCTION OF THE ENGLISH ROCK-SCHEME INTO AMERICA

Although the English classification of geological terranes was not yet a decade old Owen already incorporated it in his Iowa work. Up to the time of the appearance of Owen's report (1844), Thomas Conrad seems to have been the only American geologist who was at all inclined to recognize the new English classification. His application of it to the New York rocks was surprisingly unfortunate. During the time that he was superintendent of the New York Geological Survey and the annual reports of the four districts were being published, an attempt was made to harmonize the New York section with that of England. The effort was far from proving satisfactory. Partly for this reason and partly, perhaps, on account of the fact that the New York geologists, after Conrad had left the survey, were carried away with the idea of establishing instead of a Paleozoic sequence, a "New York System," the final reports came out, in 1843, with Conrad's plans entirely abandoned.

When, then, the second and revised edition of the "Report of the Geological Exploration of Iowa, Wisconsin and Illinois" appeared, in 1844, Owen was the only geologist in this country who had with any degree of success adapted the novel English classification of rock formations, and who had accurately determined their stratigraphic delimitations in a definite section. His earlier subdivision of the Cliff limestone into three parts of Upper, Middle and Lower, were here called Upper Shell Beds, or Devonian, the Middle Coralline Beds, or Upper Silurian, and the Lower Lead-bearing Beds, or Lower Silurian. These several subdivisions were, he astutely remarks, also distinguished by their contained fossils; and he enumerated and illustrated some of the most characteristic forms.

As pioneer of pioneers Owen was a man of remarkably keen insight into matters geological. The acumen which he, in a perfectly virgin country, displayed in deciphering the problems which successively presented themselves would have done credit to any one, even the geologist of today. In our state, in Missouri, and in Minnesota, I have personally in the field gone over much of his work, and I have had repeated occasion to verify his recorded results in

[13]Rept. Geol. Surv. Wisc., Iowa and Minn., 638 pp., 1852.

detail. I cannot but express the warmest admiration for his great skill in unravelling difficult problems, his remarkable accuracy of observation, and his invariable sound geological reasoning. In his methods of investigation three unique features are conspicuously presented. His plan of correlating geological outcrops more or less widely separated geographically by means of the combined evidences of lithologic resemblance, stratigraphic continuity, and continuity of lithologic sequence, and of plotting sections along exposed lines of streams, preceded by a generation their general adoption by American field geologists. By half a century he anticipated modern geologic requirements, when he defined his terranes by clearly noting, as essential elements of exact definition, their topographic expression, their geographic extent, their lithologic character, their stratigraphic delimitation, their biotic definition, and their economic content. In soundness of logical deduction his generalizations stand every test. All of these characteristics are repeatedly displayed for the first time in the published results of his investigations in Iowa.

One of the curious analogies which his keen penetration established was a remarkable parallelism which he seemed to find existing between the sequence of Carboniferous limestones as displayed in Iowa and the succession worked out by Phillips in England. The comparison clearly indicates the great influence which his English training in geology had upon him.

GOVERNMENTAL LEASING OF MINERAL LANDS

A recent proposal, which has been received by the public with great acclaim, is for the government to hold the control of mineral lands as public domain and lease claims to miners and operators. Whatever may now be the merits of the plan it is certain that it once had fullest trial in Iowa and proved to be a most dismal failure. Its immediate effects upon the mining industry, which at that time was quite flourishing, were the most disastrous ever experienced. Mining in this state never recovered. For long years it was practically ruined.

It was in 1807, soon after taking possession of the Louisiana Purchase, that the United States government announced a new policy respecting the development of mineral lands. It was a number of years before the scheme could be put into operation. Such lands were especially reserved. In Iowa-land nearly 200,000 acres were thus set aside. A system of leases was ordered. By paying the government a royalty of 10 per cent individuals were permitted to extract ore for a period of three or five years.

During the years immediately following the promulgation of the new ruling large numbers of prospectors and miners entered the region. Curiously enough they made agreements with the Indians rather than with the government. It was not until 1816 that the Indian rights were definitely defined and a "tract five leagues square on the Mississippi river, to be designated by the President," which the Indian treaty provided, was located in the lead region. The first leases from the government were not executed until the beginning of 1822, when four miners from Kentucky located 160 acres each. They were protected by a detachment of United States soldiers.

After granting the leases the government often failed to stand by the owners thereof. Soon continuous strife prevailed among the miners. They began to pay little attention to the regulations, but carried on operations without license, and with the aid of the Indians. Where there was one lease granted there were a score of unlicensed miners. So disastrous to all concerned was the experiment of leasing and so inconsequential was the revenue derived from this source that Congress finally, in 1846, abandoned the plan, and a year later placed the lands on the market for sale. Little wonder that during these years such remarkable industry was displayed by the "Indians," as was from time to time reported. A United States Indian agent, who passed through the region in 1810, recorded that the Indians were finding mining more profitable than hunting and were producing during that year 400,000 pounds of the metal.

INAUGURATION OF THE NEW YORK SYSTEM IN THE WEST

In the third and fourth decades of the last century New York geologists were enaged in working out a detailed stratigraphic section of their rocks. So complete was this sequence that they became ambitious to establish for the world at large a New York System, after the fashion of Murchison's Siluria and Sedgwick's Cambria in England. But the New York section proved to be too large, and to embrace a succession of superior rank. It was found to be about the equivalent of what we now call the Paleozoic section, thus including Murchison's, Sedgwick's and Lonsdale's systems. Following Murchison the New York geologists gave geographic titles to their formations, which names have spread to all parts of the country.

When, then, at the solicitation of Governor Grimes, James Hall was called from New York to conduct the newly established geological survey of Iowa, he at once proceeded to transplant the New

York rock-scheme and nomenclature to our state.[14]. Hall was not entirely unfamiliar with the western field. Some time previously he had made an extensive geological trip through the upper Mississippi valley with the special object in view of extending the New York System. He had already the aid of Nicollet, Owen and others, who had established a close parallelism between eastern and western sections. So, when he reached Iowa, as state geologist, matters were already disposed very much to his liking.

In introducing the New York classification into Iowa Hall appears to have displayed the same intense prejudice against the new English scheme that he did a decade earlier in his eastern reports. There is no mention of the English systems in his table of geological formations. The noting of them on the accompanying map seems to have been done by other hands. For many years the New York formational names given by Hall to western terranes were much in evidence in the geological literature on the region. Gradually these titles were displaced as unsuitable, until at the present time few of them remain.

But the English scheme proved fundamental and in its essentials was adopted the world over.

DETERMINATION OF THICKNESS OF IOWA ROCK FORMATIONS

The conspicuous service which Dr. C. A. White rendered the state was the determination of the thicknesses of the various geological formations. In the main these figures were reasonably correct. Without any deep-well records to serve as checks on the estimates the results are often surprisingly close. The vertical extent of the Cretacic rocks of the northwestern parts of the state and of the coal measures of the southwestern portions are especially noteworthy.[15]

The great economic value of White's estimates of rock thicknesses was, of course, the purposes which they served in furnishing clues to local underground geology. They were especially helpful in a region so deeply mantled with glacial drift as Iowa is. As guides to boring deep wells for artesian waters, to prospecting for coal and to search for other mineral wealth deeply hidden, their wide serviceability was in after years recognized by the present state survey and similar work was entered into exhaustively. White's work served its purpose for a period of more than twenty-five years, until newer figures could supplant the older ones.

[14]Geology of Iowa, 2 vols., Albany, 1858.
[15]Geology of Iowa, 2 vols., Des Moines, 1870.

EVOLUTION OF PALEOZOIC FISHES

When in the early '70's of the last century Orestes St. John, an Iowa youth, first attacked the problems concerning the ancient fishes few forms were known to occur below the Carbonic horizons. The great wealth of material of this description was just beginning to be discovered in Iowa and the adjoining states. After completing his work on the Iowa geological survey, St. John turned his attention to the fossil fishes. Large collections had been made at Burlington, Keokuk, and other parts of southeastern Iowa. Under the tutelage of the elder Agassiz, the foremost authority on fish life, our Iowan began his labors along these lines.

The measure of St. John's wide researches on the character and development of the Paleozoic fishes is found in the numerous memoirs which were issued in rapid succession and the several more pretentious monographs, all of which amply testify how extensively he contributed to our knowledge of the subject. Although working so long and so far from his native state it is a singular coincidence that he should have found in these distant places that the main collections consisted of materials obtained from his old home. Through his almost uncanny skill in reconstructing these ancient organisms Iowa became famous the world over.[16]

St. John's efforts did not stop at merely pointing out the genetic relationships of the old fishes, or in delineating their structures. His descriptions are complete, lucid, illuminating. Few of the forms which he described need redefinition—even after the elapse of fifty years. Large numbers of forms were noted and pictured as new to science.

GARDEN OF STONE LILIES

As is now generally known, Iowa is the most celebrated district in all the world on account of the prolific occurrence of remains of those beautiful fossil forms popularly called stone lilies or stemmed feather-stars. It is to Iowa men that we are mainly indebted for a monumental work on these curious forms of bygone life. Already three large volumes are published. "North American Fossil Crinoidea Camerata"[17] is one of the unique literary productions in new world paleontology. Although the senior author, Charles Wachsmuth, of Burlington, was not permitted to see the completion of this prodigious work, the investigations go on with unabated vigor under the undefatigable labors of the junior colleague, Frank

[16] Illinois Geol., Surv., Vol. VI, 1875.

[17] Memoirs of Mus. Comp. Zool., 3 Vols., Cambridge, 1895.

Springer, another Iowa scientist. In direct continuation of this paleontological *chef d'ouvre* other volumes are now in press.

Notwithstanding the fact that the work is first of all morphological in character from the foundation up, and the product of inquiries more thoroughly grounded in biological philosophy than any other research perhaps ever undertaken in this country, the published results are of such high utility in stratigraphy, especially in the broad Mississippi basin, that it may be truly said no other one publication has ever furnished so valuable criteria for the purposes of exact correlation of geological formations.

Of all fossil remains of organisms none are more admirably adapted to morphological study than those of the echinoderms. On account of their abundance, their peculiarities in geographic and geologic distribution, and their notable structure, the stalked feather-stars, or stone liles, are pre-eminent. With the skeletal parts composed of regular plates, or ossicles, definitely grouped and frequently highly sculptured, all structural changes are readily traced.

The systematic arrangement of the crinoids as proposed by Wachsmuth and Springer is one that will require but few material modifications for a long time to come. Based, as it is, upon morphological principles, with a completeness and wealth of ontogenetic and phylogenetic data that are rarely obtainable among fossil organisms, the essential elements of classification are more firmly grounded than perhaps in any other group. No attempt in recent years towards a natural and orderly arrangement of a large and complex assemblage of organic remains has been so signally successful. Nor has the evolution of the various types in time and space been neglected.

Although the morphological and classificatory chapters of the monograph on North American Crinoids appeal more directly to paleontologists interested in the biological side of the subject, the descriptive portions are of greatest practical value to stratigraphical geologists. This portion of the volumes is a complete revision of the different forms up to the time of publication. Every species is fully and clearly described, compared with closely related forms, beautifully illustrated, and referred to its proper geological horizon. All the forms are described anew from the most perfect materials that could be found in all museums and private collections.

DUALITY OF THE GLACIAL PERIOD

Admitting that Louis Agassiz's theory of continental glaciation to be one of the most brilliant generalizations of modern science, it

is neither so complete nor so widely applicable as was at first supposed. What is even more important to its scientific value than the mere statement of the conception alone is the recognition of the fact that there is not one, but many, glacial epochs in the earth's history. Of course Croll's hypothesis provides the necessity of successive glacial periods, but it soon becomes apparent that his astronomical dates are too far apart to satisfactorily account for the vicissitudes of the epoch which we are now mainly studying. So we have to go back to the testimony of the glacial deposits themselves for our fundamental data.

The arguments for a dual glacial period, and at the time of its proposal, for a multiple ice age, were based chiefly upon the fact of the presence in certain till sections of thin black soil-streaks, replaced here and there by thicker peat-beds. That there might be such a thing as extensive interglacial sands or loams was not thought of. Yet they were actually observed, recorded and fully described a complete decade prior to the time when their true significance was pointed out. Such an interglacial loam deposit, intercalated between two thick till-sheets, is the one exposed on Capitol Hill, in the city of Des Moines. It was fully described[18] in great detail by W. J. McGee so far back as 1882. It seems to be the first expression of the phenomenon ever recorded the stratigraphic relations of which were unmistakable.

At the time when these observations were made the possible complexity of the Glacial Period was not even yet surmised. Possibilities of a Second Glacial Epoch were only vaguely being considered. The prolix and bitter controversy on the duality versus the unity of the Glacial Period was just beginning. Under these circumstances it was not at all surprising that some of the phenomena observed on Capitol Hill were partially misinterpreted; and that the true significance of others was for a considerable time overlooked. Then, too, the prevailing theory of the lacustrine origin of the loess tended to obscure the proper understanding of the accurately recorded data.

Notwithstanding the fact that McGee was inclined at the time to attach rather slight importance to his observations and to regard the phenomena as indicating merely local advance of the ice-sheet, it soon became manifest that the two till-blankets separated by a thick loess deposit was impeachable testimony in support of two distinct and great ice movements within the span of what was previously

[18] American Jour. Sci. (3), Vol. XXIV, pp. 202-223, 1882.

regarded as a single one. So far as is known this appears to be the first and most important recorded evidence showing conclusively the complex character of the Ice Age.

Of similar import was the somewhat later description of a great drift section several miles farther south on the Des Moines river. In a paper read before our Academy, in 1890, it was shown that there was still another thick interglacial member to be reckoned with below the till-sheet underlying the loess. In later years officers of the Geological Survey were inclined to regard it as representing the pre-Kansan Aftonian sands and gravels.

As it is, our fellow Iowan narrowly escaped making one of the great half dozen geological generalizations of the nineteenth century—the establishment of the fact of the complexity of the great Ice Age.

PHYSIOGNOMY OF ANCIENT CONTINENTAL GLACIERS

The landscape expression of our state during glacial times is vividly set forth in fancy by W. J. McGee, in his great memoir[19] on the "Pleistocene History of Northeastern Iowa." At the time when the fieldwork was chiefly done the idea of a possible duality of the Glacial Period was new. Suitable criteria for correlating observations had yet to be formulated. The character of the phenomena were also unique in the annals of geological science. Here are McGee's own words as he pictures the conditions: "The most startling induction of geology, if not of modern science, is the glacial theory; but in the solution of the problem it is necessary to do more than assume the existence and action of the great sheet of ice hundreds or thousands of feet in thickness and hundreds or thousands of miles in extent. In order to explain the sum of the phenomena it is necessary to picture the great ice-sheet not only in its general form and extent but in its local features, its thickness, its direction and rate of movement over each square league, the inclination of its surface both at the top and the bottom, and the relation of these slopes to the subjacent surface of the earth and rock; and all this without a single stria or inch of ice-polish, save in one small spot, in the whole tract of 16,500 square miles. It is necessary to conceive not only the mode of melting of the ice at each league of its retreat, but also every considerable brook, every river, and every lake or pond formed by the melting, both at its under surface and on its upper surface; it is necessary to restore not only the margin of the *mer de glace* under each minute of latitude it oc-

[19] Eleventh Ann. Rept. U. S. Geol. Surv., pp. 110-577, 1893.

cupied, but, as well, the canons by which it was cleft, the floe-bearing lakes and mud-charged marshes with which it was fringed, each island of ice, and each ice-bound lake formed within its limits. And it is not only necessary to reconstruct the geography of a dozen episodes, as does the anatomist the skeleton from a few bones, but to develop the geography such as civilized eye has never seen, and which could exist under conditions such as utterly transcend the experience of civilized man. All this has been done. The trail of the ice monster has been traced, his magnitude measured, his form and even his features figured forth, and all from the slime of his body alone, where even his characteristic tracks fail."

COMPLEXITY OF THE GREAT ICE AGE

Iowa's role in the establishment of glacial succession was peculiarly fortunate. In the world-wide controversy which raged for more than a generation our state bore a conspicuous part. It was in Iowa that the first real evidences were found indicating a multiple instead of a unal character for the Glacial Period. They were Iowa men who made this telling discovery. In Iowa were differentiated not one but five prodigious drift sheets marking successive advancements of the vast fields of northern ice. On Iowa men devolved mainly the responsibility of first working out the complete and genetic relationships of these remarkable till mantles. Today the Iowa classification of the great Ice Age epochs is accepted by the whole world.

In order fully to appreciate the genuine importance of the Iowa results bearing upon glacial complexity as opposed to glacial unity the facts leading up to the birth of the conception may be briefly reviewed. So early as 1870 Edward Orton observed peatbeds intercalated in the glacial deposits of Ohio, and he rightly concluded, as it afterwards proved, that this feature indicated a warm interglacial epoch. He stated that evidences were now at hand for an orderly arrangement of post-Tertiary deposits. This dual aspect of the glacial debris was further substantiated by Leverett, Chamberlin, Gilbert, McGee and others. In the prolix discussion which necessarily followed, on the duality of the Glacial Period, the real facts were overlooked or misinterpreted, and the possibility of a multiple instead of either a unal or dual Ice Age was lost sight of completely. Once suggested, however, the multiple hypothesis, about the year 1893, gained general acceptance among scientific men.

It is a quite noteworthy circumstance, as Prof. R. D. Salisbury recently points out, that Prof. Samuel Calvin, of Iowa, who, after

a lifetime's devotion of his geological energies to investigation in totatally different fields, should suddenly turn to glacial geology with such signal success, and such notably productive results. In his presidential address before the Geological Society of America, at Baltimore, Professor Calvin gives a summary of the "Present Phase of the Pleistocene Problems in Iowa,"[20] in which the five subdivisions of the Glacial Period are distinctly outlined. These furnish the clue to the glacial history of our entire continent and of the world. Comparing these results with what was known twenty years before, it is forecast that another twenty years of effort will disclose other ice advancements of which we now know nothing.

CLIMATIC INDEX OF INTER-TILL DEPOSITS

Notwithstanding the fact that continental glaciation is a topic of absorbing interest, it is one of the grand triumphs of modern science to furnish such indisputable proofs that there existed in late geological times a prodigious polar ice-cap reaching so far down as the Ohio and Missouri rivers. Even until a generation or two ago few persons had intimation that an arctic climate had prevailed so recently over so large a part of the northern hemisphere. The conception of this veritable Ice Age stands out as one of the scientific novelties of which, says a recent writer, "our century may boast and which no previous century ever so much as faintly adumbrated."

While the majority of the glacialists were studying the evidences of glaciation one of our own Iowan sons, Prof. Frank Leverett, was directing much of his attention to the consideration and analysis of the deposits separating the several till-sheets.[21] So important were his conclusions that we now seem justified in assuming that the warm periods between the successive ice advances were as pronounced in their duration as the respective epochs of arctic climate. The necessary inference is that today we are living in the very midst of a typical interglacial time.

The evidences of these warm interglacial climates are now as abundant and as complete as are those of refrigeration. In supplying facts bearing upon this vague phase of the subject Iowa takes first rank.

SYSTEMATIC REVISION OF THE FOSSIL CRINOIDS

Since the lamented demise of Doctor Wachsmuth the latter's co-worker, Mr. Frank Springer, has carried on the investigations

[20] Bull. Geol. Soc. America, Vol. XX, pp. 133-152, New York, 1909.

[21] Mon. U. S. Geol. Surv., Vol. XXXVIII, 817 pp., Washington, 1899.

long ago jointly begun. Although Mr. Springer has delved alone into the subject for more than twenty years his results cannot be very well separated from those which were formerly carried on with his distinguished colleague.

The second installment of the great publication is now about to leave the press. All of these unique *recherches* from beginning to end may be regarded as having been initiated and accomplished in our state. It is to be regretted that Iowa could not have the pride to give birth in print to the grandest scientific and philosophic offspring she ever conceived. A distant state and a guardian government less slow to recognize the spark of genius, snatches from her the one greatest honor of a century.

All in all the systematic description, classification and illustration of the fossil crinoids is the most conspicuous single effort of the kind ever undertaken in this country. It is truly a colossal contribution to our knowledge of ancient life. Of all places of earth Iowa is the one from which it ordinarily might be least expected to emanate.

The continuation of the work soon to appear will equal that already published.[22] It is devoted entirely to the Flexibiliate forms, and will be superbly illustrated by an atlas of 100 large plates.

GENESIS OF THE SILICIOUS LOAMS

With the establishment by Iowa of systematic investigation of the natural phenomena under the ægis of a state survey the larger geographical problems rapidly took form. As data accumulated the various themes became circumscribed, and resolved themselves into fields all their own. Were it not for the tutelary supervision of the survey our geological knowledge might be still floundering in the slough of medievalism. First announcements of the results of many of these inquiries which were of more than local import or of world-wide interest, appeared in the Proceedings of our Academy.

Among the first of these moot questions to be imposed upon the attention of the officials of the survey was the derivation of the vast deposits of fine silicious loam, which we designate by the title of loess, and which mantle so much of our state.

The belief almost universally held by earth students that the deposits of silicious marls associated with the till-sheets were of glacial or lacustral origin long prevailed. In China it was long ago suggested that this loess was wind-derived, but the idea never, until recently, gained foothold elsewhere.

[22] North American Crinoidea Flexibilia, 3 vols., 4 to. Washington 1920.

Nevertheless, in Iowa, in spite of an adverse consensus of opinion, the peculiar distribution of the loess loams appeared to be such as seriously to call into question the verity of the accepted notion. On Capitol Hill, in Des Moines, thick loess deposits were displayed interbedded with tills. Later these sections gave first intimation of the possible wind-born character of the formation.

In after years loess was observed in the actual process of formation by means of the dusts blown off the Missouri river sandbars and from the dry upland plains of Kansas.[23] Still later the loess was identified with the adobe soils of western deserts.

It was on Capitol Hill, also, that first clues were found pointing to that wonderful interlocking of the continuous adobe mantle of the Southwest with the glacial till sheets of the Northeast.[24].

DIASTROPHIC TAXONOMY OF ROCK TERRANES

One of the larger problems connected with the coal investigations undertaken by the state survey was following the strand-line of the continental interior seas. The usual criteria of fossils proved unavailable partly because of the relative shortness of the time involved and partly for reason of the constant recurrence of the faunas. Although the reappearance of organic forms at successive horizons was no doubt a direct function of the oscillation of the old shore-line the nature of the biotic changes admitted of no definite characteristics upon which classificatory schemes could be established.

Recourse, therefore, had to be made directly to the coal measures themselves for testimony concerning their history. It so chanced that upon the epicontinental sea area the episodes of stratigraphical development proved to be unusually well marked. The practical outcome of the new plan was strongly contrasted by comparison of the resulting summary[25] of the Iowa formations with the general sections previously outlined.

The principles involved promised to be more than merely local in application. In recent years they were widely applied to distant parts of our continent. They were finally recognized the world over. It is probable that before many years have passed they will have entirely supplanted the usual criteria of the organic remains. In stratigraphy, therefore, diastrophism takes on a fundamental and genetic character.

[23] Am. Jour. Sci., (3), Vol. VI, pp. 299-304, 1898.
[24] Am. Jour. Sci., (4), Vol. XXXIII, pp. 32-34, 1912.
[25] Iowa Geol. Surv., Vol. XXII, pp. 154-155, 1913.

TERRANAL EQUIVALENCY OF UNCONFORMITY

Iowa's coal measures, as is now generally known, rest with marked discordance of strata upon the rough, tilted and beveled edges of all the older geological formations of the region. These unconformable relations are very widespread. This break in continuity of succession at the base of our coal-bearing series clearly represents an old land surface that was subjected to the forces of erosion for a period long enough for sloping strata to be planed off from the Carbonic limestones down to Cambric sandstones. In the interval between the deposition of the last of the early Carbonic formations and the coal measures of the upper Mississippi basin enormous regional denudation really took place. The magnitude and stratigraphic significance of this erosion was long little appreciated.

Commonly the phenomenon under consideration was regarded as local in its nature. Unconformities occurred at many different horizons in the coal measures. That this basal discordance was really a great hiatus was never fully considered. That the space represented an epoch much longer in duration than that in which was formed all the coal measures above it was a most startling phase of the problem presented.

The base of the Des Moines series, or lowest horizon of the coal measures of Missouri, was believed to extend southward beyond the Arkansas river, where it appeared to coincide with the Grady coal, or base of the Cavanoil formation. With the base of the Des Moines series of Missouri thus approximately located in the Arkansas section, and the top of the early Carbonic horizon well defined, it left in the south an immense thickness of nearly 19,000 feet of coal measures sediments that were entirely unrepresented in the north.

The magnitude of the hiatus at the base of the coal measures in Iowa, Missouri and Kansas, is the more readily comprehended when we find a place where uninterrupted sedimentation attained such vast proportions as 19,000 feet in vertical measurement. The epoch of which there is no measurable record in one part of the region finds in the adjoining district sediments of greater stratigraphic significance than all the coal measures above the break.[26] It is a case in which on one side of an old shore-line is the land area that suffered profound denudation, and on the other the water area in which sedimentation was carried on to a prodigious extent. In point of time the one is the exact equivalent of the other.

[26]Bull. Geol. Soc. America, Vol. XII, pp. 173-196, 1901.

SCHEMATIC STANDARD FOR AMERICAN CARBONIC ROCKS

As the Iowa Carbonic section began to expand it became manifest that there were considerable portions of it which were to be found in better representation elsewhere. When, finally, certain guide-horizons were traced from outcrop to outcrop southward across Missouri into Arkansas and southwestward into Kansas the section gradually assumed extraordinary completeness. It resolved itself into what was the most perfect section of the entire country, perhaps of the world. This fact at once pointed out its possible availability as a standard scheme for the American continent.[27]

Nine-tenths of this great section are represented in our state only by an unconformity plane; yet taking into account its southern extension its chief merit is its exceptional completeness. No other section of the Carbonic rocks on the continent possesses such an enormous thickness. The several series of the general succession appear to be more sharply defined than anywhere else. Few columns have the base so abruptly cut off from the Devonic terranes below. At the top Cretacic strata often rest upon it in marked unconformity. Instead of attempting to fit the Mississippi valley section into that of Pennsylvania, as is usually done, effort is far more fruitful of satisfactory results by bringing the rock succession of the latter into accord with the former. Also, in place of trying to extend the Mississippi basin classification to the Rocky Mountain region the formations of the latter are best apposed to those of the first mentioned.

Until recently, more or less difficulty in securing results that are even approximately satisfactory have always attended the efforts to parallel the various provincial sections of the Carbonic succession. The sections of the East, of the Interior, and of the West appear at first glance to have no comparable elements. These discrepancies are now all removed. The out-standing features are the completeness and great thickness of the Mississippi Valley succession. It is most imposing rock section of which we know.

Apparently influenced mainly by such consideration as these Professor Chamberlin is inclined to emphasize the time significance of our coal measures depositions and in the general classificatory scheme give the span they occupy an exalted taxonomic rank equivalent to Period. There are, however, essentials other than those of thickness. The mere fact that the column of sediments measure 20,000 feet does not necessarily remove the terrane from the serial class.

[27] Iowa Geol. Surv. Vol. II, Coal Deposits, pp. 162-171, 1894.

EXPANSE OF COAL HORIZONS

Very unexpectedly Iowan coal measures in yielding up their secrets lately brought into perfect harmony the two diametrically opposed hypotheses concerning the disposition of coal beds, a problem which was the subject of bitter controversy for many years the world over. On the one hand it was contended that there existed a strict parallelism in the stratigraphic relations of coal seems. On the other hand it was held that coal beds were always set at an angle to one another; they split, came together, diverged.

Stratigraphic analysis of a circumscribed Iowa coal basin disclosed the fact that the two opposed views were not really contradictory. Paradoxically as it seemed both were true. The main difficulty was that the two conclusions had only resulted from an approach of the theme from distinct angles. The one idea proved to represent a cross-section of the coal-bearing strata taken parallel to the general course of the shore-line; the other conception represented the structure at right angles to the strand-line.[28]

In other words approach to parallelism, or divergence of coal seams is a direct function of local diastrophism during Carbonic times. Instructive and interesting as this generalization is its practical aid to prospecting and development is of infinitely greater significance. Its importance in mining economy can hardly be over estimated.

Thus practically visualized coal horizons come to have an industrial meaning not usually ascribed to them. In stratigraphy, a geological horizon is a level recognizable over a considerable area, having a more or less well-defined stratigraphical position, distinctive as to lithologic features, and characterized by a particular set of fossils. In a broad sense the term is almost equivalent to formation, and is used about as indefinitely. In its more limited meaning it is applied properly to a minor part, or zone, of the smallest stratigraphic unit having a commonly accepted specific name. Understood in the same way, a "Coal Horizon" represents an even more limited expansion, where coal-forming materials have accumulated. In reality it is one of the greater planes of sedimentation, marking an episode in the deposition of a series of strata. Theoretically it represents not a phenomenon but rather a set of conditions, or a period during which the physical circumstances were similar over a considerable marginal portion of a geologic province. From an economic angle it stands not for a

[28] Journal of Geology, Vol. II, pp. 178-186, 1894.

continuous bed of mineral fuel but for a stratigraphic level where workable coal is to be especially sought for in a wide belt fringing a great basin.

CONTINENTAL TERRANAL CORRELATION BY OROTAXIS

What continues today to bother the geologist more perhaps than any other subject relating to earth knowledge is the problem of exact stratigraphic correlation. It is, indeed, a phase of geology which has been a source of embarrassment ever since the science's birth two centuries ago. When, during the last quarter of the last century, stratigraphy began to demand quantitative rather than qualitative results other stratal criteria had to be found which in the field are of even greater practical value than could be hoped for with the fossils. When comparisons are made with other criteria the shortcomings of the paleontologic methods become glaringly unsatisfactory. Closely examined the paleontologic scheme of geologic classification is found to be not an arrangement of terranes at all, nor a logical table of historic events, but merely a rather imperfect grouping of faunas. The question arises whether in stratigraphy we should not be better off today if we were to ignore the fossils altogether, or recognize them only in a general way.

As originally defined[29] orotaxis, or stratigraphic classification upon the basis of diastatic or diastrophic movements is essentially as follows: Immediate cause for the changes which take place in the relations of the land and the sea areas is is to be sought in orogenic and epeirogenic movements. Since, however, the two kinds of crustal oscillation cannot be readily distinguished practically, and as it is of small advantage to separate them theoretically, the structural results produced may be regarded as arising from the same cause—that is, from mountain-making forces. The greatest and most abrupt modifications in sedimentation, and consequently in lithologic, faunal and, in fact, all characters, are those connected directly with diastatic activity, producing depression of some areas and the uprising of others. Geologic chronology is believed, therefore, to find true and rational basis in those changes which primarily control sedimentation, and which are intimately connected with the genesis of mountains. It is proposed to emphasize this feature as fundamental by marking out the leading subdivisions of geologic time and to define general stratigraphic succession in accordance with the cycles of orogenic development, calling the classification a systematic arrangement of mountains, or orotaxis.

[29] American Geologist, Vol. XVIII, pp. 289-303, 1896.

The nicety and rapidity with which the orotaxial principles act in practice are indicated by a number of specific determinations. Furthermore, in the Upper Mississippi Valley the relative values of the different methods of correlation are capable of exact comparison.

In the present advanced stage of stratigraphical science, when reconnaissance work is no longer needful over a large part of our country, it appears that we have reached a point at which classification of geologic terranes begins to follow definite rules in accordance with the taxonomic ranks of the several geologic units, much in the same way that it is accomplished in botany or zoology. We may arbitrarily recognize the larger subdivisions as world-wide time units; and regard the sediments as deposited during certain cycles, or periods. The latter may also be again subdivided and still retain the time criterion. Below the taxonomic rank period, or sub-period, geologic sections become provincial in character. By clearly distinguishing between geologic history and biotic history geologic correlation is placed upon a rational, genetic, and philosophic foundation. Thereby is stratigraphy immeasurably advanced.

MOUNTAIN STRUCTURES UNDER THE PRAIRIES

That mountains should once spring forth where now is level land is one of the scientific novelties of our State. Of all places on earth the flat and monotonous plains are the last place where one would be inclined to look for traces of Alpine scenery. Yet mountains here there once surely were, albeit they now are completely vanquished, leveled to the sea, lost and forgotten. That there lie buried under the surface of the smooth illimitable prairie land the remains of a high and mighty range is a circumstance almost inconceivable. Although at the present day the suggestions of these old mountains are inconspicuous they are many. Through means of records of deep-well borings and other data, the height, extent, and form of the ancient mountains are fully figured forth and their characteristic features pictured out.

This great earth-wrinkle, which sprang from the sea in Mesozoic times, extended from the east shore of present Lake Superior southwestward beyond the path of the Missouri river. Medially the strata were bowed up more than a mile above the existing level of the prairies. In their prime these Siouan Mountains rivaled in scenic beauty and stately grandeur the Adirondacks, the southern Appalachians, or the Juras of today.

The sudden appearance and rapid decline of the Siouan Mountains on the mid-continental horizon is an incident of a by-gone age. Brief, brilliant, almost pathetic are the succession of chief events. The main uplifting took place during the Triassic period. In the succeding Jurassic and Comanchan times all of the ranges were completely razed to the present plains-level. During Cretacic time the waters of the sea again rolled unbrokenly over the old base-leveled plain, and the bared foundations of the former lofty mountains made up the bottom of a broad epi-continental sea. No great orogenic uplift was ever more rapidly or completely obliterated. It was one of the marvelous episodes in the long history of the North American land contest.[30]

SUBEQUAL SPACING OF CRUSTAL RUPTURES

Profound faulting is commonly associated with mountain development. In a plains region, and especially in sea-level basins of a continental interior, notable displacement of strata is about the last tectonic feature that one expects to encounter. The recent location in the Upper Mississippi Valley of a number of fault lines of considerable moment is one of the surprises of geologic inquiry in this region. Singularly Iowa appears to have been the locus of repeated crustal rupturing on a large scale.[31]

Both in our own state and in neighboring states, lately, some of the long neglected problems of regional tectonics have been attacked from new and unexpected quarters. Novel data have been obtained. Long known but isolated facts have been reviewed, reinterpreted, and re-correlated. The trend of the most fruitful lines of investigation has been pointed out. In Iowa, particularly, results quite disconcerting have been reached. Attention already has been directed to the vast Triassic mountain-building which took place within our boundaries. Especial interest, also, has been attached to the recent determination of the distinct synclinorial character of the Iowa coal-basin. Further, note has been made of another instructive phase of regional tectonics and the discovery of what has appeared to be two well-defined systems of faulting on a major scale, that has heretofore eluded detection.

The lines of faulting of the two systems trend nearly at right angles to each other. In the system which prevails in the eastern part of the state the direction of fracture is northwest and southeast. The amount of displacement is large. The spacing is wide.

[30] Proc. Iowa Acad. Sci., Vol. XXI, pp. 181-187, 1914.
[31] Proc. Iowa Acad. Sci., Vol. XXIII, pp. 103-112, 1916.

The ruptures are long and somewhat curved. In the other set, which is confined to the western portion of the state, the value of the movement figures is not nearly so great as in the case of the other; yet it is still quite notable. The space between faults represents a distance of about twenty-five miles. This figure suggests the spacing value of the entire system. Plotting upon the map of the state other lines to mark possible positions of other faults we find abundant indications of the presence of such features.

In partial explanation of this phenomenon we get an inkling from a neighboring source. It is a well known fact, established through extensive experience in mining operations, that when the interval between two parallel faults is determined other faults are expected to exist at like intervals. This circumstance is directly traceable to the nature of the tortional strains which rock-masses undergo. Whether or not such a high spacing value as twenty-five miles is actually possible remains to be determined theoretically. The problem is readily susceptible of mathematical demonstration, as in the cases of fault-systems of much closer pattern. It would be exceedingly instructive to apply the principles involved to the Iowa situation.

ANTIQUITY OF IOWA'S OLDEST ROCKS

Of late years the stratigraphic level of our lowest rocks is pushed back immeasurably. Now they rank with the oldest of any of which we have knowledge on the face of the globe. Terranes older than those of the Paleozoic age occupy in Iowa a very small surface area. Attention which is bestowed upon them is about commensurate with their relative surface extent. Heretofore, one finds that little attempt has been made to determine their broader stratigraphic relationships, their real position in the general geologic column, their possible subdivision, or their role in the geotectonics of the region. It seems all sufficient merely to note the existence of these rocks in the extreme northwestern corner of the state. Yet these very rocks now appear to have a history longer, more complicated, and more vicissitudinous than that of any other terrane represented within our borders.

For the first time we recently learn that some of these pre-Cambrian rocks are very much younger than was once thought to be the case; and that others are very much older. For the first time, also, we are now able to compare them with a standard section of the most ancient sediments known, that very complete and satisfactory classificatory scheme of the Lake Superior region

adapted from Lawson's scale. Our rocks prove to be really an integral part of these northern masses, a long tongue of which extends from the Great Lake southwestward into Iowa and South Dakota.

The stratigraphic aspect of the Iowa pre-Cambrian rocks is fundamental. At this time the special geologic significance of the terranes of which they are an integral part, lies in the circumstance that they have suddenly acquired world-wide interest on account of the fact that they supply critical data for evaluating the duration of the pre-Cambrian periods. They give us a basis of comparison of the mid-continental section with the Paleozoic successions as we best know them. They enable us to formulate a systematic scheme of pre-Cambrian stratigraphy that is comparable in its variety, its complexity, its detail and extent, with the post-Cambrian standard which has been evolved during the course of the past century.

That wide interest aroused by the recent discoveries of abundant well-preserved organic remains in rocks of undoubted pre-Cambrian, and hence pre-Paleozoic, age is secondary only to the enthusiasm produced a few months ago by the actual location of the fossiliferous horizons in the general geological column. As definitely determined these oldest fossil-bearing levels are stratigraphically more than two miles beneath all other known horizons yielding traces of life. These revelations are, of course, as important biologically as geologically. They materially modify all of our previously held views on the subject. They open up a more inviting field of investigation than awaited the paleontologists of the first half of the last century when they started to unravel the life record preceding Cretacic time. They promise even greater triumphs than when the Paleozoics first revealed their secrets to Murchison, Sedgwick and Lonsdale.[32]

Thus to the bottom of the general geologic column as usually presented in the textbooks of the science, we are inserting a scale of fossiliferous formations the time-span of which equals or even surpasses in duration that covered by the entire Paleozoic succession.

ORIGIN OF EPIROTIC DEPOSITS

In commenting upon the potency of the wind as an erosional agent the late W. J. McGee astutely observes that the satisfactory disposal of the rock-waste of the desert by prodigious eolic exportation supplies the missing link to a rational explanation of all those

[32]Proc. Iowa Acad. Sci., Vol. XXIV, pp. 53-60, 1917.

long puzzling pheneomena presented by arid regions throughout the world. With the exportation and disposal of the dusts of the desert comes their disposition elsewhere. It is in connection with the last mentioned phase that Iowa plays such an important role.

In the recent consideration of subærial formations so many novelties enter that in many an old and familiar field a new interest is aroused. Prominent among such tracts is the country lying between the Rocky mountains and the Mississippi river. Both for the origin of the plains surface itself, and the unconsolidated deposits which immediately underlie it, no very satisfactory explanation is found except recently.

On a grand scale the Great Plains seem to introduce to us a mode of terranal genesis that has long passed unrecognized. Continental deposits thus begin to assume in this country an importance never before accorded them. The constant aggradation of the region appears to be due mainly to the potent activity of the winds.[11]

Concerning epirotic, or continental deposits several essential points are to be noted. They are as important as either marine or lacustrine terranes. On the whole American eolic deposits are of vast extent. They are being formed under conditions whereby they may be preserved through the geologic ages as effectually as any of the Cambrian formations have been. In this new century the theory of eolic planation, transportation and deposition promises to be one of the great and novel thoughts in the domains of geology.

PRE-GLACIAL CROSS DRAINAGE OF IOWA

Assuming with Powell that of all physiographic features the rivers are the most permanent one looks about for clues to what might be the drainage expression of our state before the continental ice-sheets covered the land. Present drainage is, we know, entirely a post-Glacial consequence; so there is manifestly no relation between it and that which existed prior to Glacial times. Except the small area around Dubuque every vestige of the ancient river courses is more or less deeply hidden by the till. In order to get at what prevailed before the coming of the glaciers we have to remove in fancy the great drift mantle.

Some insight into the character of Iowa's pre-Glacial waterways is obtained by consideration of the present streams which are outside of the drift-mantled area. In Tertiary times the lowest line of the continental interior depression was no doubt occupied

[11]Bull. Geol. Soc. America, Vol. XXII, pp. 687-714, 1911.

by a master-stream much in the same position as it is today. By the elevation of the Rocky mountains the rivers in the west must have been directed eastward down the long gentle slope until they finally reached the old Mississippi. Their present ending with the Missouri river is a later, or Glacial, consequence. At any rate several of the primitive streams must have continued entirely across the states of Iowa and Missouri.[34]

In marked contrast with the present smooth surface of our state the relief which prevailed at the end of Tertiary times and immediately before the first great ice invasion presents extreme differences of altitude of between 300 and 500 feet. Over the old elevations the drift is often scarcely more than a score of feet in thickness. In some of the old depressions and valleys the Glacial deposits are as much as 500 feet thick. The disposition of the low places is such that they lie in long belts or gorges having relatively steep sides. Some of these primitive troughs are manifestly the paths of extinct rivers. The one so well know at Des Moines is now followed far beyond that neighborbood. Its narrow belt is traceable northwestwardly to Sioux City where it unites with the gorge of the Missouri river.

EPI-CONTINENTAL ORIGIN OF GYPSUM DEPOSITS

Iowa's massive beds of gypsum being among the most famous in the country the mode of genesis attracts wide attention. So closely is their deposition always associated with the drying up of empounded waters of the ocean that any possibility of their having been formed under conditions other than those involved in the evaporation of sea-water is expressly precluded.

Quite recently to be sure, we now find that gypsum beds accumulate on a large scale far away from the influence of the sea. They are being extensively developed today on the highest and driest part of our continent. Dunes of gypsum sands that are vastly more pretentious than any of our Iowa beds accumulate under the activity of the winds. The fact that in Tertiary times western deserts probably extended eastward over the state suggests that our gypsum deposits, too, may have been segregated under conditions of excessive aridity.

The recent determination of the geologic age of the Iowa gypsum deposits, that the date of their origin is not Carbonic, nor Permian, nor Triassic, nor even Cretacic, as has been repeatedly advocated

[34] Proc. Iowa Acad. Sci., Vol. XXV, pp. 551-561, 1919.

at different times, but that it is probably Miocene, or Mid-Tertiary, has deep significance. It places at once the gypsum and associated Pink shales among true continental, or epirotic, deposits—accumulations on dry land and entirely independent of sea, lake, or river.[35]

FACETED FORM OF A COLLAPSING SPHEROID

Comparable with some of the work in the physical, chemical and engineering laboratories are some of the recent experimental inquiries initiated in geology in our state. It sometimes seems strange that in a prairie state like Iowa this laboratory experimentation should take the trend of the larger problems in geotectonics. In a line of research such as geology presents where the materials used are so largely dependent upon the immediate surroundings the selection of a topic that rests not upon place, matter or method is a decided novelty. Several widely different experiments have been recently completed.

In certain experiments lately performed in which heavy, rolled paper was used, the amount of collapse is measured by the diurnal change in the humidity of the air. On wet days the result is a surface of singularly large and perfect rhombohedrons. With paper not so tough relatively, or with the use of some brittle substance, no doubt rupture would take place along the edges of the facets. In all practical respects the lines of the great mountain upheavals of the globe are exactly located.

The application of the principles to teluric conditions is obvious. It is not necessary to postulate a cooling globe in order to consider the geometric effects of partial collapse. Because of the fact that with a given mass the body with the greatest surface area is a sphere, and the one with the least surface a four-sided form, it is sometimes argued that our planet is tending towards a tetrahedral earth. In the final analysis, however, it is indicated that the crystallographic form could hardly be so simple, but would result in a shape in which each facet of the ground-form consists of a number of smaller facets. The rhombic dodecahedron best fits the figure which the major mountain chains outline on the surface of the globe.[36]

MERIDIANAL DISPOSITION OF THE CONTINENTAL MASSES

In its basal significance our prevailing notion concerning continental mass is strictly geographic. In its definition tectonics finds

[35] Eng. and Mining Jour., Vol. C, p. 466, 1915.
[36] Bull. Geol. Soc. America, Vol. XXIX, p. 76, 1918.

no place. Relation of land and sea is made causal and essential; whereas it is only accidental and trivial. The outstanding feature is a broad basin with high mountainous rim, and low sea-level interior. Recent experimental reproductions of those broad basinal tracts which correspond to the oceanic depressions of the geoid are accompanied by results having curious significance. They point to the fact that we shall have to modify our fundamental conceptions concerning all the major deformations of the earth's crust.

Instead of distinguishing between continental elevations and oceanic depressions the proper discrimination to be made is between the cordilleran ridges of the continental borders and the intervening lowlands whether above the level of the waters in the continental interior, or below sea-level in the existing oceanic areas. The meridional disposition of the continents then comes to be readjusted as relatively narrow orographic ridges in place of broad basin-shaped plateaus.[87]

OROGRAPHIC DEFORMATION THROUGH DIMINISHING RATE OF EARTH'S ROTATION

From the results of recent curious experiments in geotectonics conducted within our boundaries it is inferred that the larger relief features of our globe are not really the complex dynamical phenomena commonly fancied but that they are all merely somewhat different expressions of the same simple tangential force and direct resultant of the earth's rotation.

Inquiry into the immediate origin of the great earth wrinkles is usually approached from an astronomical angle. Since on the assumption of a cooling globe the contractional hypothesis takes form it is premised that the earth passes through much the same course as does a shriveling apple.

As is well known, a rotating spheroid possessing notable elasticity does not have the geometric radius coincident with the radial line of molar equilibrium, or repose from stress. The first is a straight line; the second a section of a parabolic curve the focal coefficient of which varies with the rate of revolution. For obvious reasons the spheroid of the laboratory acts as a homogeneous body. Extending these physical principles to the earth complications at once set in. The zones of rock-flow and rock-fracture necessarily behave differently. The former acts as a homeogeneous body under hydrostatic pressure. The latter develops the characteristics of a heterogeneous body: it flexes, faults, and shears; and gives rise to all of

[87] Science, N. S., Vol. L, p. 413, 1919.

those tectonic phenomena which are commonly accounted for on the hypothesis of a contracting nucleus. Tangential compression thus may be initiated without regard to a cooling globe.

In laboratory experimentation on curved prisms, with bands corresponding to gravitational control, and with conditions under which there is gradual release of rotational stress analogous to retardation of the earth's rotation, there is reproduced to a nicety all of those larger structural features of the earth such as the ocean basins, the continental arches, cordilleran corrugations, and orographic foldings. The effects of tangential creeping which many mountain structures display thus appear to be not necessarily the result of earth's contraction but of direct cumulative stress-release due to secular retardation of the earth's rotation.

The bearings are far reaching. On this new basis, with the force and rate of retardation, and the amount of crustal shortening capable of exact expression by mathematical equations a ready means is provided for realizing not only something of Elie de Beaumont's fantastic dream of orographic symmetry, but for gauging in units of human time the age of every mountain uplift, for determining within very narrow limits in like terms the periodicity of every diastrophic movement, and for evaluating in years not only the span of every era and period, epoch and stage of the stratigraphic record since life appeared on our globe, but stratigraphic chronology long antedating the life record.[38]

GEOLOGICAL SURVEY OF IOWA

The collection of data concerning the mineral features of our state has now been carried on systematically and without interruption for more than twenty-five years. These have been years of exceeding productivity. Along with the more strictly scientific phases have gone on hand in hand an exhaustive investigation of our mineral resources. Thirty sumptuous volumes amply attest the vigor with which the work has been prosecuted. Many different workers have been engaged upon the myriad of problems presented. Varied as the results have been it has been surpassed by novelty.

Monumental inquiry of this kind is, of course, necessarily composite in character. The investigations are conducted by all earth students of the state, reinforced at times by chemists, physicists and engineers, and even by zoologists and botanists. Altogether the combined efforts make a most creditable showing. No other state

[38] Bull. Geol. Soc. America, Vol. XXX, 1919.

in the Union matches ours in the volume and general excellence of the published results. Of the geological information published relative to our state a digest alone covers a large volume of nearly a thousand pages.[89]

That a public scientific work should endure for a quarter of a century without interruption and without sudden changes of policy, weather the vicissitudes of unsympathetic legislatures, and overcome the prejudices of an indifferent people, is a circumstance mainly due to protective clauses in the organic law establishing the organization. Directly under the ægis of our Academy and our two great universities, capable scientific men guide its activities. The highest scientific talent of the state is always at command. By the simple provision of an *ex-officio* board of management control of the survey is entirely removed from insidious political influences, and the selfish interests of local cliques. Support of the work being by annual appropriation it is unnecessary to beg before an occupied legislature every biennium.

EPILOGUE.

Several years ago one of our Academy's worthy presidents, a zoologist by the way, in attempting to measure up the annual output of creative endeavor, incidently resorted to some comparative statistics. Unwittingly he drew attention to the fact that of Professor Cattell's eight "starred" men of science apportioned to our state, four were geologists. This remark called forth rather bitter response from the chemists, who would ascribe the ascendency of the earth students to the public financial aid which they received. A little reflection disclosed to all present that there is deeper reason than this really inconsequential material advantage.

Singularly, Iowa geologists are prone to hook up their local *recherches* with problems of world-wide significance. In attempting to unravel the earth puzzles at home they also, by showing their bearing upon the broader problems, tend to do their bit in promoting knowledge generally. Their work thus becomes a part not altogether of curious home information alone, but an addition to the sum total of philosophical knowledge. Iowa takes active part in world discussions. Provincial workers pass from mere local to national or even world-wide sympathies. If, therefore, the Iowa geologists have any appreciable advantage over their *conferes* in other branches of science it is not due so much to slight material help, but principally to the acquirement of catholicity of sympathies

[89]Iowa Geol. Surv., Vol. XXII, 908, pp. 1913.

and of a broad and comprehensive manner of doing things of universal interest.

If fifty per cent of Iowa's "starred" men of science are geologists it is equally noteworthy that one-half of them do not happen to be connected with public bureaus or universities at all. The honor of becoming a "starred" man in any department of intellectual activity is certainly great. That all of Iowa's leading men of science are active members of this Academy is a matter of considerable state pride. It is surely a distinct personal achievement for any one of us to win a place for himself among the one thousand leading men of science in a country of a hundred million people, to attain during his generation especial eminence, to maintain himself as a commanding figure in the advanced thought of the nation, and to acquire something of a reputation throughout the world.

Iowa's geological century seems unusually replete with achievements of large moment.

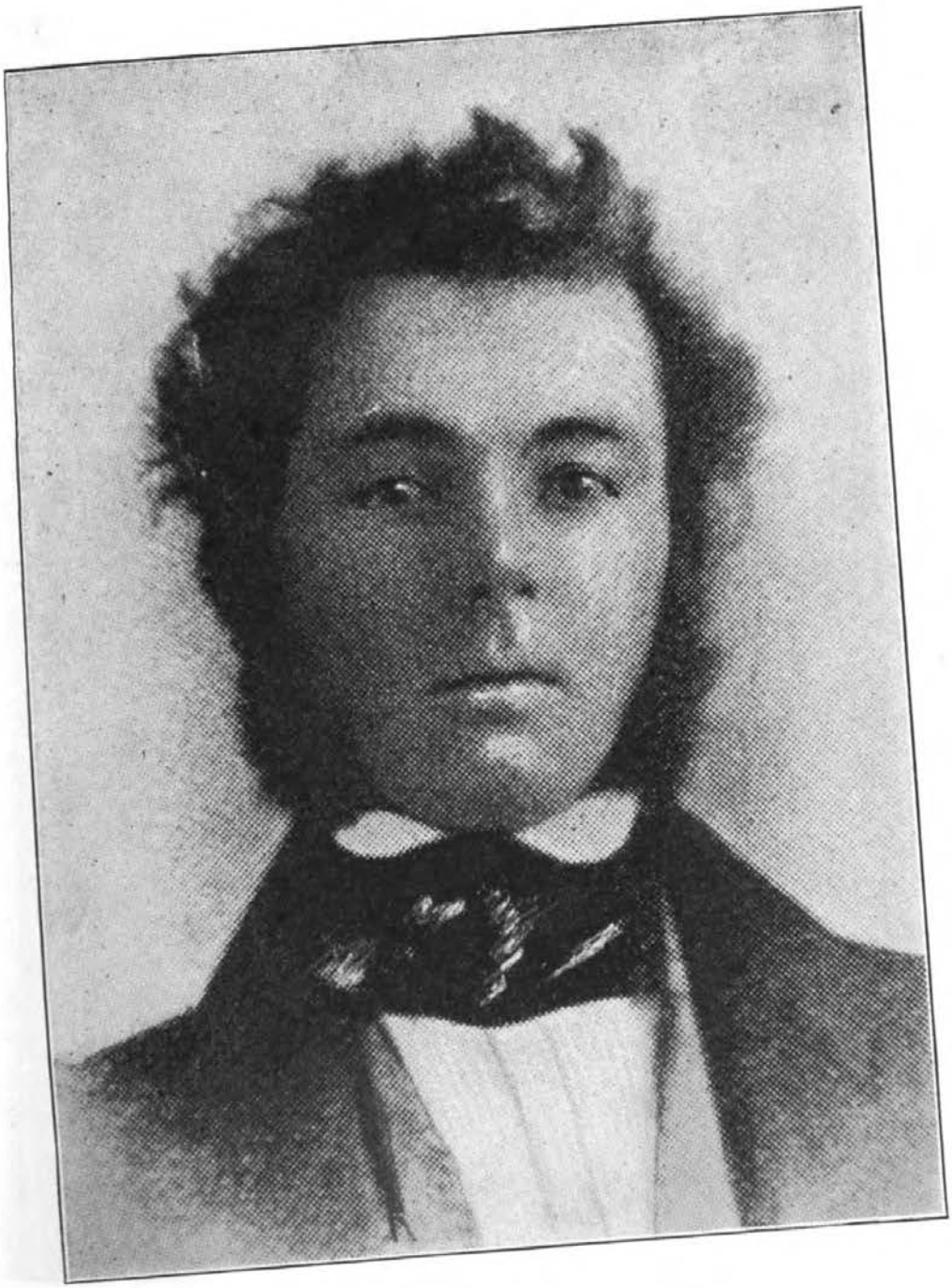
Thos Nuttall

Edwin James

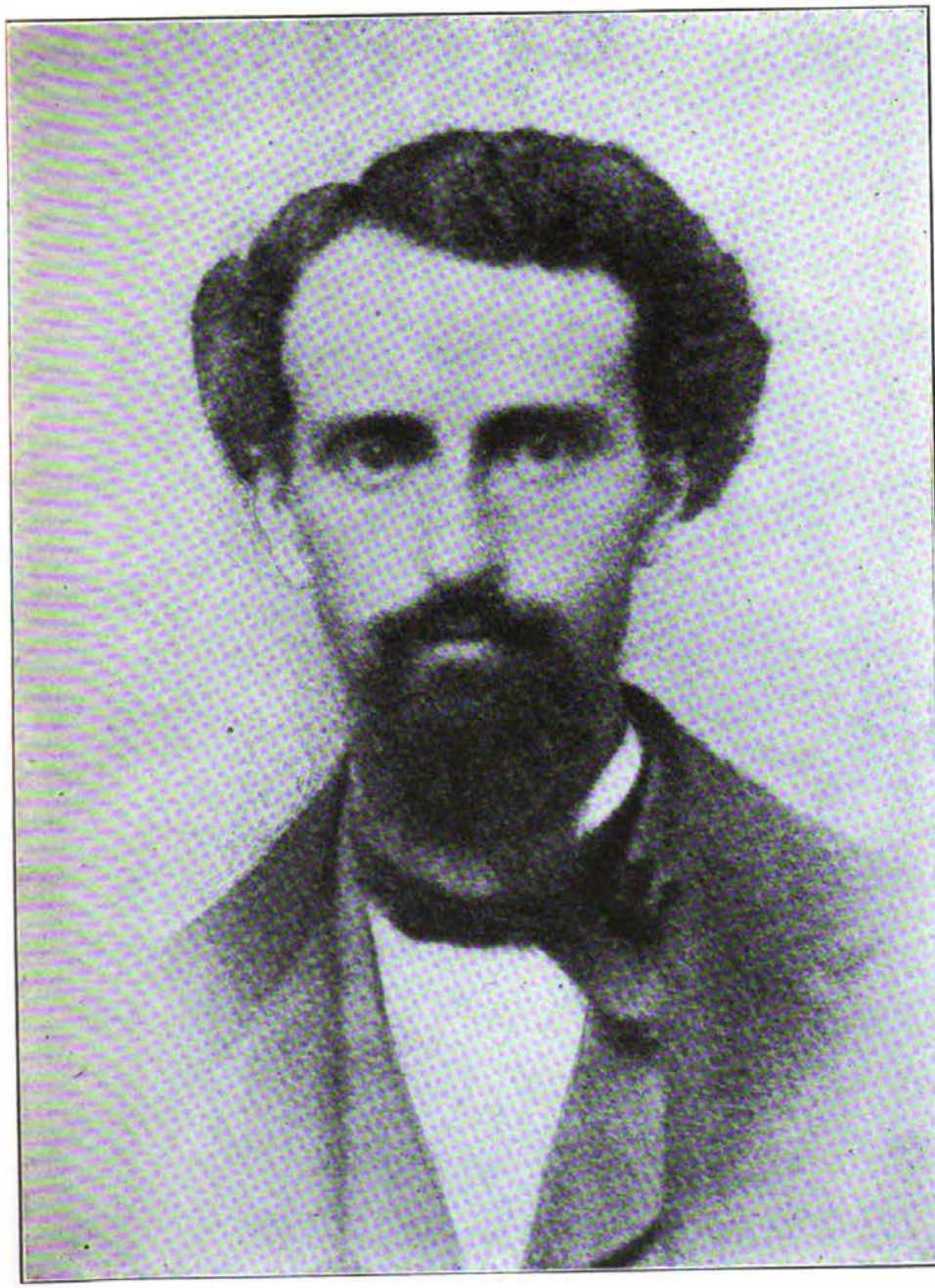
Henry R. Schoolcraft

J. N. Nicollet

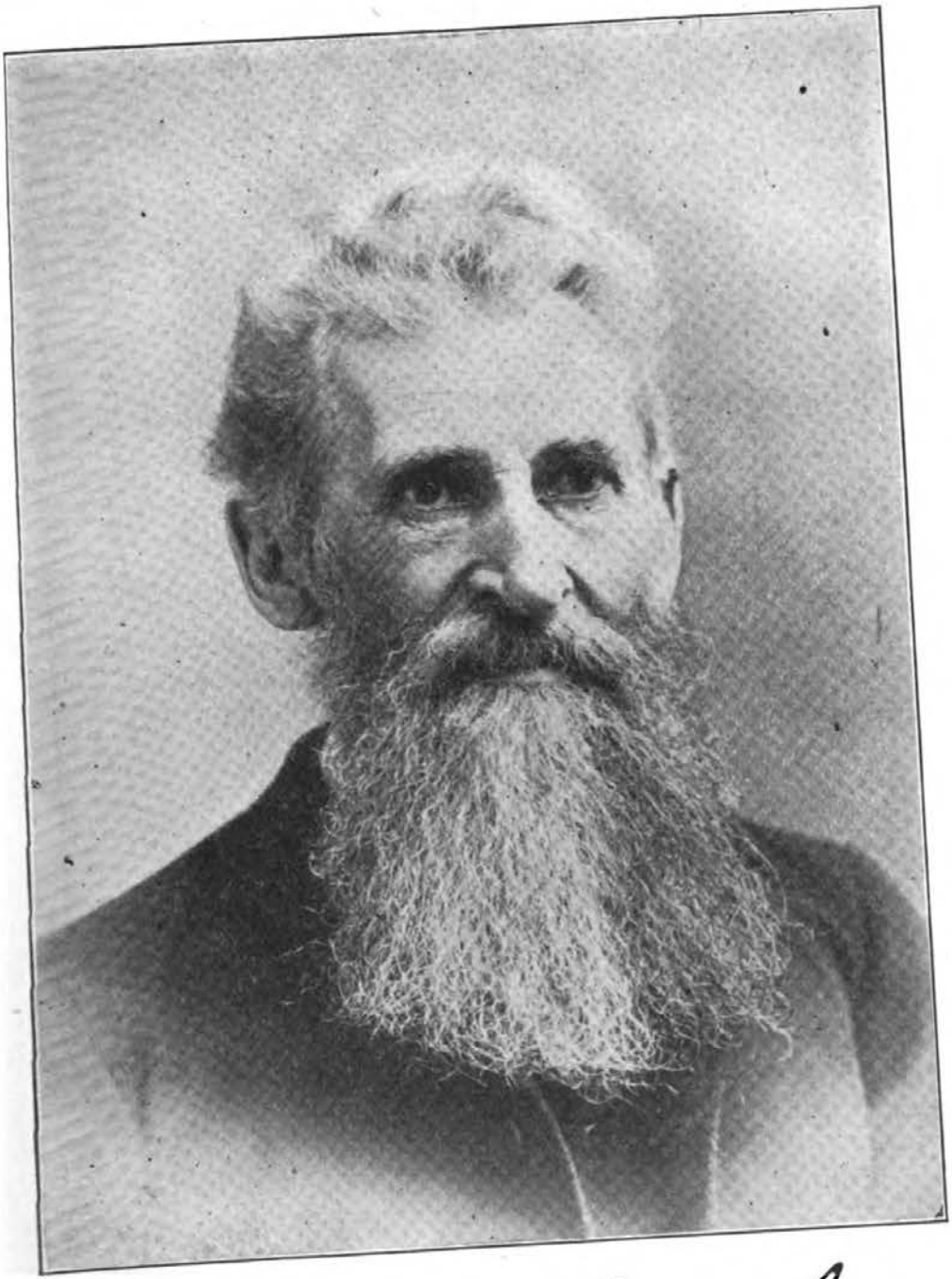
D. D. Owen.



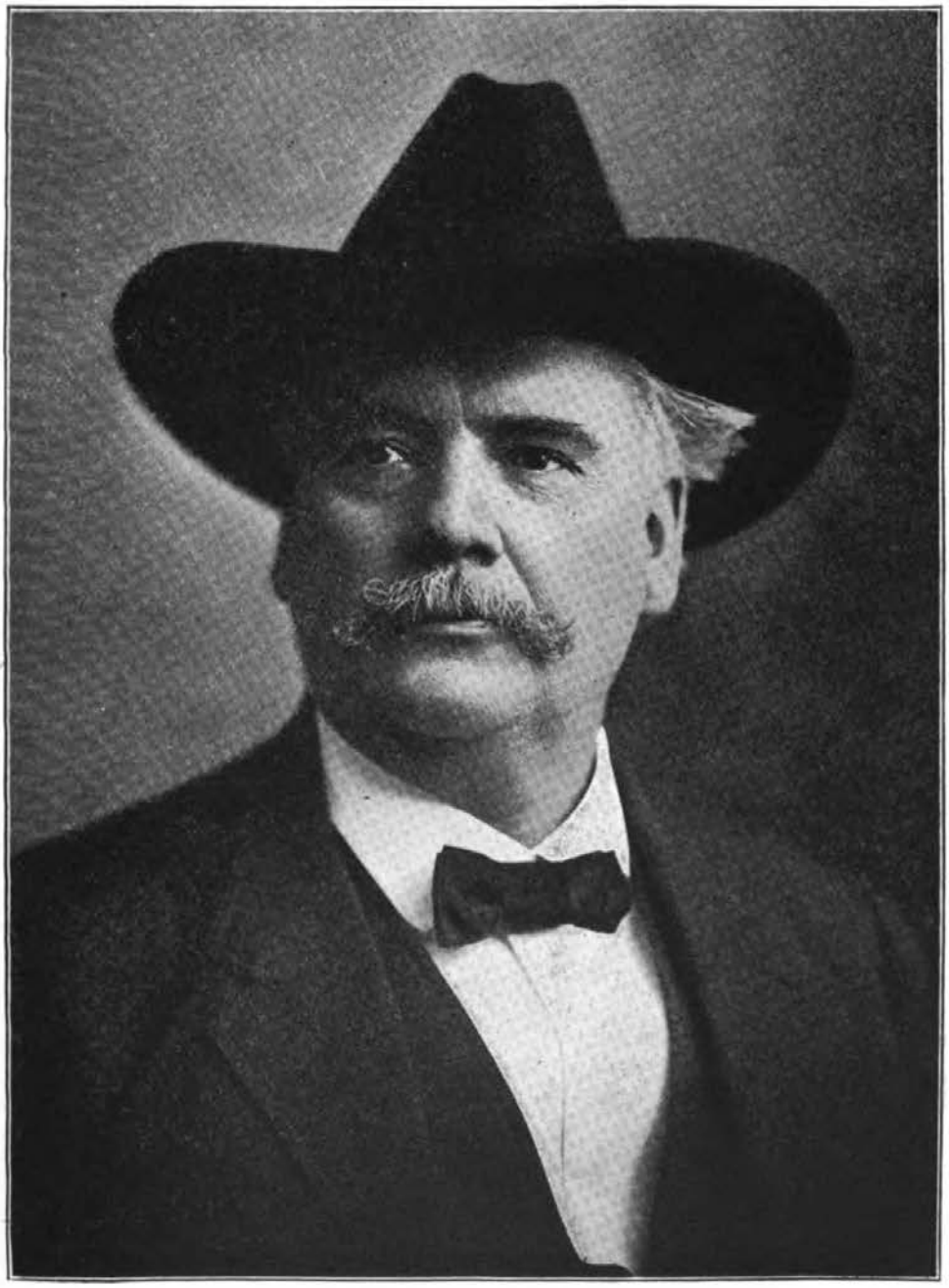
James Hall
State Geologist



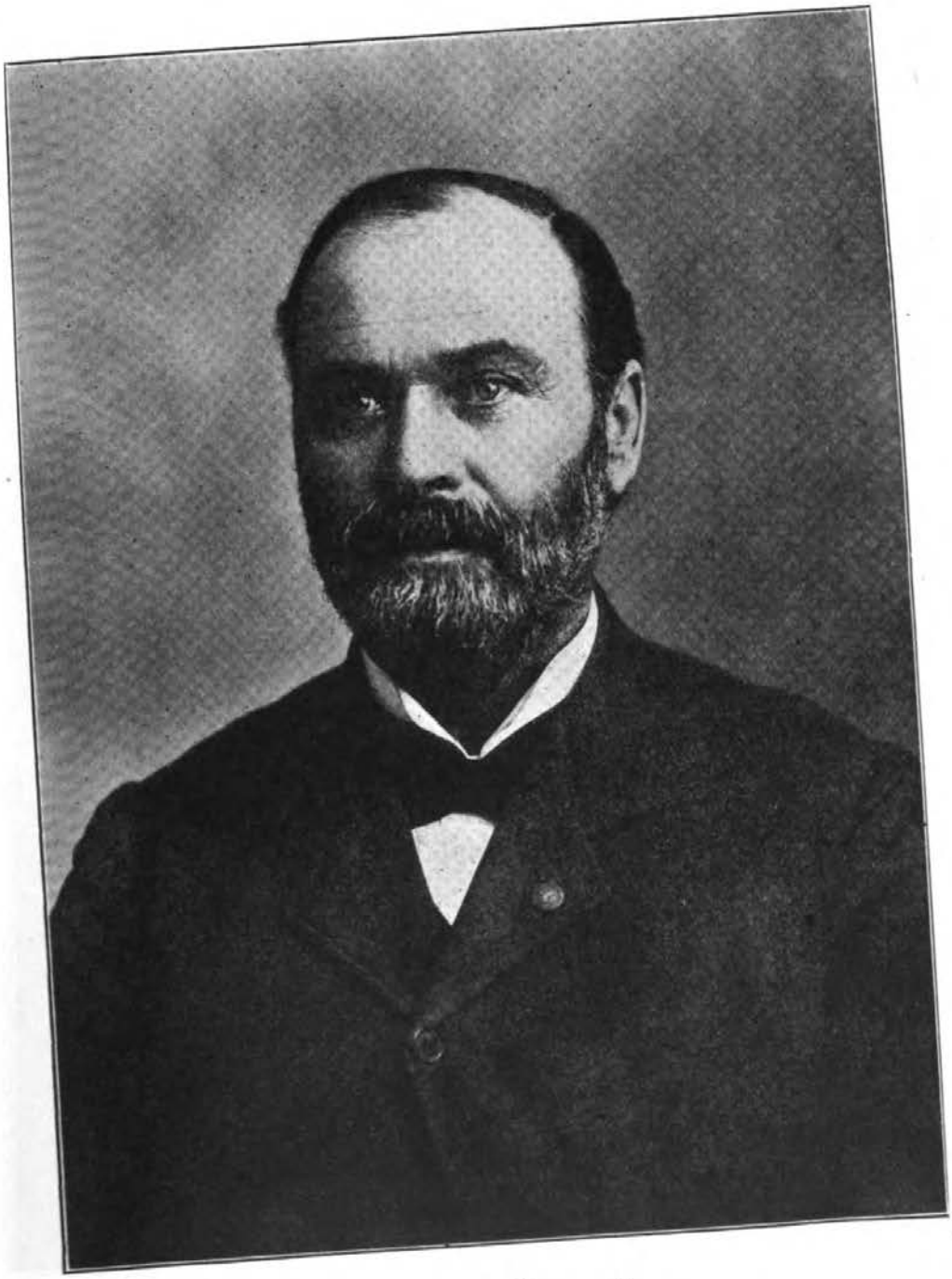
Yours most sincerely,
Charles R. Keyes.



Charles Rachsmuth

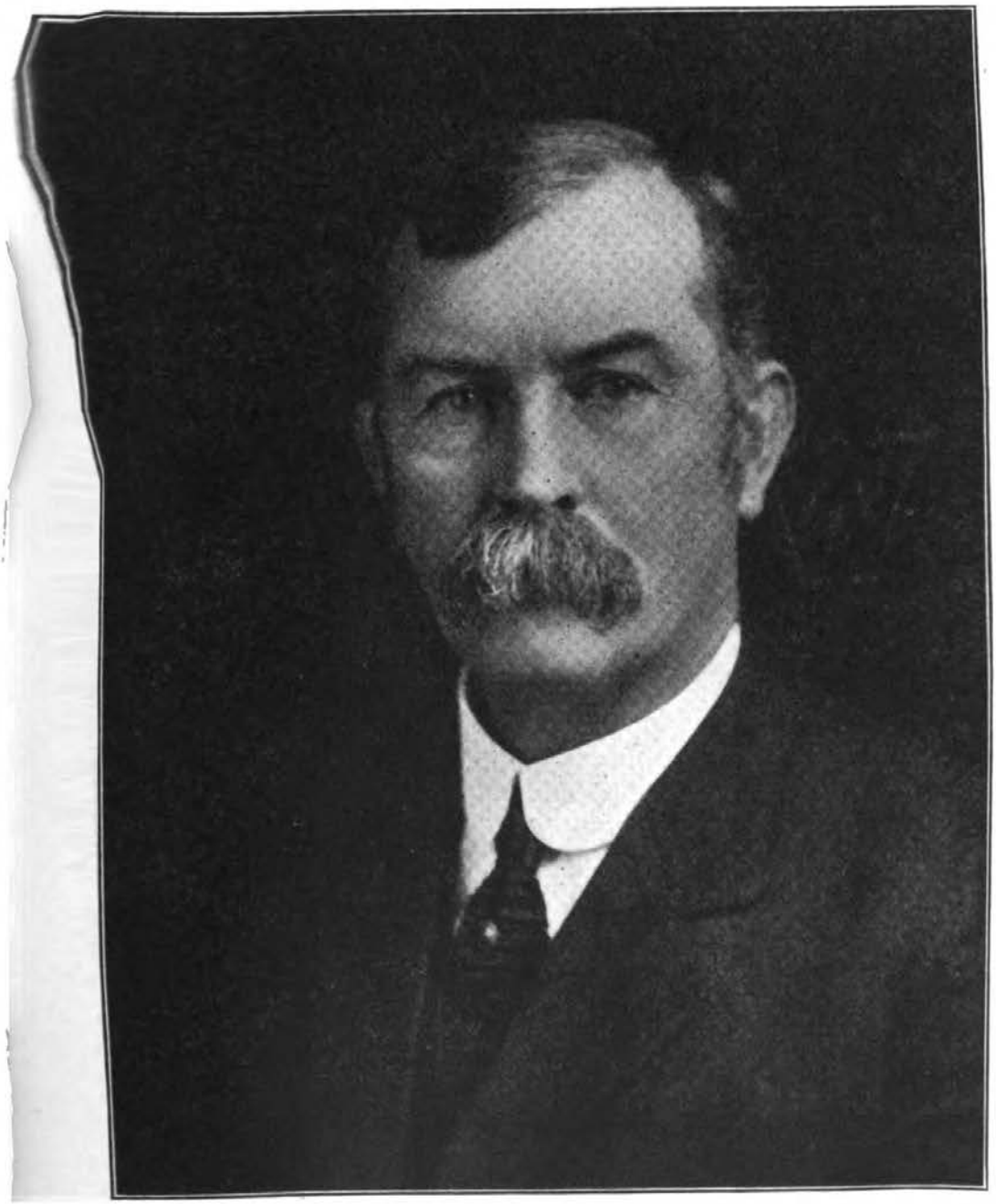


W J McGee



Yours very truly,
Samuel Calvin.

Yours Truly
Frank Leverett.



Frank Springer